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For: A COMBINED SOURCE-CHANNEL DECODING METHOD AND AN ASSOCIATED  
COMBINED SOURCE-CHANNEL DECODER

**DECLARATION**

I, Andrew Scott Marland, of 11, rue de Florence, 75008 Paris, France, declare that I am well acquainted with the English and French languages and that the attached translation of the French language PCT international application, Serial No. **PCT/FR2005/000645** is a true and faithful translation of that document as filed.

All statements made herein are to my own knowledge true, and all statements made on information and belief are believed to be true; and further, these statements are made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any document or any registration resulting therefrom.

Date: July 21, 2006

A handwritten signature in black ink, appearing to read 'A. Marland', with a stylized flourish at the end.

Andrew Scott Marland

A single horizontal line drawn in black ink, extending from the left towards the right, positioned below the signature.

A COMBINED SOURCE-CHANNEL DECODING METHOD AND AN  
ASSOCIATED COMBINED SOURCE-CHANNEL DECODER

The present invention relates to a combined source-  
channel decoding method. It also relates to an  
5 associated combined source-channel decoder.

A particularly advantageous application of the  
invention is to coding and decoding digital data  
transmitted over a communications channel, in particular  
MPEG (Moving Picture Expert Group) data transmitted over  
10 UMTS mobile telephone channels.

The digital communications systems offering the best  
performance at present use source and channel coding  
systems that are optimized separately. The source coder  
minimizes the redundancy of the source signal to be  
15 transmitted. In contrast, the channel coder introduces  
controlled redundancy to protect the information from the  
interference that is inherent to any kind of  
transmission.

In concrete terms, the best audio, image, and video  
20 source coding results are obtained by discrete cosine  
transform (DCT) coders or wavelet coders associated with  
variable length codes (VLC). Where channel coding is  
concerned, turbocodes, and more generally soft decision  
iterative coders, represent a decisive step towards the  
25 theoretical limit defined by Shannon, but optimum  
separation of source coding and channel coding is  
guaranteed only for codes whose length tends towards  
infinity. Because of this, the optimum solutions  
achieved in practice, with channel codes of finite  
30 length, lead to optimizing combined source-channel coding  
and/or decoding systems.

Considerable work has been done on these systems  
recently, in particular on variable length codes which  
represent the most critical situation in that a single  
35 error can propagate over entire segments of the bit  
stream before the receiver is able to resynchronize.  
Several combined source-channel coding and/or decoding

methods have been proposed. One of their common features is the necessity to use the source statistic to improve the overall performance of the decoder under given transmission conditions. Authors usually assume that the  
5 decoder knows this statistic exactly. In practice, this is not the case for real signals, especially for non-stationary source signals, as in the application to MPEG4 transmission over UMTS channels referred to above.

There are four prior art categories of solutions for  
10 decoding variable length codes, for example of the Huffman type, transmitted over degraded transmission channels known as noisy channels, with or without channel coding:

15 a) Separate decoding or tandem method.

In that method channel and source decoding are effected sequentially and independently. Source decoding involves looking up information in tables and therefore corresponds to what is referred to as hard decoding. In  
20 that case, the coder and the decoder need only to know the variable length code table and the decoder requires no additional source statistic information. Tandem decoding using hard source decoding is the standard decoding scheme in prior art communications systems.  
25 European patent 1 230 736 refers to tandem decoding with turbocoding used for channel coding.

b) Decoding methods with perfect estimation of the source.

30 Those methods assume that the decoder knows perfectly and definitively the structure of the variable length code tree and the associated source statistic, made up of discrete values (symbols). That statistic may be used by the source decoder, in a form of decoding  
35 known as flexible decoding, and/or by the channel decoder. In this regard, above-mentioned European patent

1 230 736 constitutes a significant advance in terms of  
channel decoding taking account of the source statistic.

5 c) Decoding methods with parametric estimation of the  
source.

Parametric modeling of real sources may be envisaged  
in some cases. For example, in the paper by A.H. Murad  
and T.E. Fuja, "Exploiting the residual redundancy in  
10 motion estimation vectors to improve the quality of  
compressed video transmitted over noisy channels",  
Proceedings of the Inter. Conf. on Image Processing  
(ICIP), 4-7 Oct. 1998, the authors propose a first order  
Markov model comprising eight parameters for representing  
the movement vectors of a sequence of animated images.  
15 The decoder can then use these parameters, which are  
estimated in the coder and assumed to be transmitted  
perfectly, to process the source statistic, i.e. the  
movement vector variable length code symbol transition  
probabilities.

20

d) Decoding methods with non-parametric estimation of the  
source.

Decoding methods that dispense with a model are  
becoming more generic and can therefore be applied to  
25 different sources. The estimation methods known at  
present relate only to estimating symbol probabilities,  
either stationary probabilities (see J. Wen and  
J.D. Villasenor, "Utilizing Soft Information in decoding  
of Variable Length Codes", Proceedings of DCC, Snowbird,  
30 Utah, USA, March 1999) or, and better, first order Markov  
source transition probabilities (see C. Weidmann and  
P. Siohan, "Décodage conjoint source-canal avec  
estimation en ligne de la source" ["Combined source-  
channel decoding with on-line estimation of the source"],  
35 Proceedings of Coresa 03, Lyon, France, January 2003).

That imposes the calculation of a number of  
stationary probabilities equal to the size of the

alphabet of the source symbols or of transition probabilities equal to the square of the size of that alphabet. In practice, that therefore rules out transmitting said information and imposes estimation in the decoder. Accordingly, a simple calculation performed for the movement vectors of the MPEG4 coder shows that the transmission of the necessary statistics (a  $65 \times 65$  matrix of real numbers for each block of 4096 bits) would require an unacceptable increase in the bit rate.

However, the above decoding methods all have a number of drawbacks.

Drawbacks of methods of type a).

The essential drawback of those methods is that they do not exploit *a priori* knowledge linked to the source for flexible source decoding or for channel decoding assisted by the source. However, considerable research based on assumptions of type b), c) or d) has shown that significant improvements could be obtained given exact knowledge or an estimate of the source statistic. Thus, for a given transmission scheme and a given channel, type a) methods constitute a lower limit in terms of performance.

Drawbacks of methods of type b).

Decoding methods that assume perfect knowledge of the source statistic in the decoder can be applied only in theoretical frameworks that are encountered relatively infrequently in practice. For a given transmission scheme and a given channel, type b) methods constitute an upper limit in terms of performance.

Drawbacks of methods of type c).

Decoding methods that use parametric estimation of the source are a first step toward practical applications. However, there are a number of omissions

in the description of the method given in the above-mentioned paper by A.H. Murad et al.

Firstly, a criticism of a general nature is that the MAP (maximum a posteriori) decoding algorithm used is  
5 extremely complex in that it is implemented by means of a decoding trellis that corresponds to the product of three elementary decoding trellises.

As for the estimation method proper, it should be noted that the eight parameters estimated in the coder  
10 are assumed to be transmitted without error and only once. That assumption ignores the fact that such transmission has a high cost. Firstly, it increases the bit rate significantly because, in practice, the movement vectors constitute a source of non-stationary events, and  
15 the parameters of the model that change frequently must therefore be transmitted on each update. Then, the cost of protecting the information transmitted by the movement parameters by channel coding, because it is highly sensitive, may be high, while estimating it in the  
20 decoder can make the model less accurate. In this regard, it should be emphasized that, even in the coder, modeling the movement vectors is relatively complex, and in the above-mentioned paper by A. H. Murad et al. the authors themselves recognize the imperfection of their  
25 model. Moreover, that model does not really correspond to what happens in reality according to the video standards where, to reduce the bit rate, a differential mode is selected for coding the movement vectors, which makes obtaining an accurate model even more complex.

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Drawbacks of methods of type d).

The above-mentioned paper by J. Wen and J.D. Villasenor is the first reference to non-parametric estimation of the source statistic in the decoder. To  
35 stop the propagation of errors, the data is encapsulated in packets and it is assumed that the decoder knows the number of bits per packet, which is generally the case.

The number of symbols per packet may or may not be known. The algorithm used by those authors is of the flexible input and flexible output type: it provides information as to the confidence that can be placed on the selected  
5 sequence. Simulations using a Gaussian additive white noise channel show a significant improvement compared to hard decoding. In a second part of the paper, the authors consider estimating the source probabilities in the decoder. They derive a forward pass, backward pass  
10 algorithm close to the Baum-Welch algorithm, dedicated to estimating symbol probabilities in a variable length code context. Apart from the fact that that technique relates only to source decoding, its major drawback is linked to its great complexity. The decoder corresponds to the  
15 implementation of a general method of obtaining the optimum decoded sequence in the MAP sense. That approach is based on dynamic programming and offers no simplified implementation. Moreover, the method is limited to calculating stationary probabilities of different  
20 variable length code symbols and therefore takes no account of Markov sources, which are of greater interest from the point of view of potential improvements in performance.

More recently, the above-mentioned paper by  
25 C. Weidmann and P. Siohan has proposed a combined source-channel coding and/or decoding technique using a module in the source decoder to estimate the statistic for first order Markov sources. Note firstly that the combined source-channel coding and/or decoding principle is based  
30 on the serial turbocoding technique with a variable length code first coder. Decoding then applies the turbocoding principle between the channel decoder and a flexible variable length code decoder. That scheme was initially proposed by Bauer and Hagenauer for a source  
35 without memory and extended afterwards by Guyader et al. to Markov sources, based each time on an MAP criterion (symbol or sequence). The estimation method described in

the above-mentioned paper by C. Weidmann and P. Siohan applies to that type of combined source-channel coding and/or decoding scheme. The source decoding portion is described in terms of a BCJR (Bahl Cocke Jellnek Raviv) algorithm using a trellis that functions at the bit and symbol level. It is then shown that a variant of the Baum-Welch algorithm expresses the estimate of the statistics of the source symbols using the BCJR forward and backward phase variables again.

Despite those simplifications, the method has the drawback of a very high complexity overhead.

Moreover, emerges in detail below, a comparison made with the assumption of perfect estimation of the source has shown that that iterative method offers worse performance than the method of the present invention for bit error rates (BER) of less than  $10^{-3}$  that are most typical of mobile radio channels (see M. Jeanne, P. Siohan, J.C. Carlach, "Comparaison de deux approches du décodage combiné source-canal pour la transmission sans fil de vidéo" ["Comparison of two approaches to combined source-channel decoding for wireless transmission of video"], Proceedings of the GretsI colloquium, September 2003).

The context of the present invention is methods of type d). Its object is to move towards, and even to achieve, optimum decoding performance, in the MAP sense, at the same time as retaining acceptable implementation complexity for mass market receiver systems, for example mobile telephones able to receive video signals.

A major drawback common to the two methods of type d) referred to above is linked to their great implementation complexity. The complexity overhead results largely from the fact that flexible source decoding or combined source-channel coding and/or decoding is effected at the symbol level.

In contrast, the present invention proposes a simple and effective method of estimating the source statistic



of variable length code symbols that is integrated at the bit level. It is based on European patent 1 230 736, which already proposes a method of flexible source decoding or combined source-channel coding and/or  
5 decoding implemented at the bit level. In particular, it is shown in the above patent that a turbocode type decoding technique can greatly improve performance if the first channel decoder of the decoder uses both the knowledge of the variable length code tree structure and  
10 the statistics associated with the branches of the tree. Depending on the source model, the useful statistic may correspond to stationary probabilities or to transition probabilities. However, all the decoding options of the above-mentioned European patent (flexible source  
15 decoding, combined source-channel coding and/or decoding with convolutional codes or turbocodes) assume that the decoder knows the source statistic perfectly, which in practice is not generally the case.

The present invention therefore proposes to improve  
20 the method of European patent 1 230 736 by adding to it a simple method of estimating the source statistic.

According to the present invention, this is achieved by a method of combined source-channel decoding of digital data coding discrete values or symbols received  
25 by a channel decoder of a digital data decoder from a source over a transmission channel, wherein probabilities associated with said symbols are applied to a channel decoding trellis of said channel decoder, which method is characterized in that said probabilities are estimated  
30 statistically from occurrences of the symbols estimated by said decoder.

The main advantages of the coding method of the invention are as follows:

· improved performance when decoding Markov sources  
35 coded with variable length codes; these improvements over a method of type a) are reflected in a lower BER (bit error rate) when transmitting on a given channel or

conversely in the possibility of obtaining a given BER using a lower transmitted power,

- for a given transmission system and a given channel, the possibility of obtaining results close to the upper limit of performance of methods of type b),

- the possibility of using a source estimation method that is sufficiently generic to take account of sources of different kinds without increasing the transmission bit rate,

- a method whose implementation complexity is relatively low compared to prior art methods of type d).

If  $\underline{i}$ ,  $\underline{j}$ , etc. denote the symbols associated with the source by source coding, according to the invention said probabilities are the probabilities  $p(i)$  of occurrences of the symbols  $\underline{i}$  or the probabilities  $p(i/j)$  of transitions between the symbols  $\underline{i}$  and  $\underline{j}$ . The probability  $p(i/j)$  (the probability of  $\underline{i}$  "knowing"  $\underline{j}$ ) more precisely signifies the probability of the symbol  $\underline{i}$  occurring after the symbol  $\underline{j}$ .

According to the invention, said probabilities are estimated iteratively by accumulating estimated symbol information at the decoder output.

Finally, in an advantageous embodiment of the invention said symbols are coded using a variable length code represented by a binary tree of finite size and said probabilities are associated with each branch of said tree and applied to the corresponding stages of said channel decoding trellis.

In practical terms, the decoding method of the invention may be implemented by a combined source-channel decoder for digital data, comprising a channel decoder adapted to receive digital data transmitted from a source over a transmission channel and coding discrete values or symbols and probabilities associated with said symbols, which combined decoder is characterized in that it further comprises a generator of histograms of occurrences of the symbols estimated by the decoder,

means for calculating probabilities associated with said restored symbols, and means for applying said probabilities to a channel decoder trellis of the channel decoder.

5        More particularly, said channel decoding trellis produces binary values and said means for applying said probabilities comprise a module for converting symbol probabilities into binary value probabilities.

10        The description with reference to the appended drawings, which are provided by way of non-limiting example, explains in what the invention consists and how it may be reduced to practice.

15        Figure 1 is a general diagram of a system including a combined source-channel decoder of the invention used to code/decode digital data received from a source over a noisy transmission channel.

Figure 2 is a general diagram of a combined source-channel decoder of the invention.

20        Figure 3 is a detailed diagram of the Figure 2 decoder in the case of turbocoding.

Figure 4 is a comparative diagram giving the bit error rate (BER) as a function of the usable signal-to-noise ratio ( $E_b/N_0$ ) for the first order Markov source proposed by Murad and Fuja, using a tandem decoding method (dotted line), a combined source-channel coding and/or decoding method with perfect knowledge of the source (continuous line), and the combined source-channel coding and/or decoding method of the invention with estimation of the source (dashed line).

30        Figure 5 is a comparative diagram giving the bit error rate (BER) as a function of the usable signal-to-noise ratio ( $E_b/N_0$ ) for a Gaussian Markov source quantized on four levels, with a correlation of 0.9, using a tandem decoding method (dotted line), a combined source-channel coding and/or decoding method with perfect knowledge of the source (continuous line), and the combined source-channel coding and/or decoding

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method of the invention with estimation of the source (dashed line).

Figure 1 is a diagram representing the transmission of digital data from a sender consisting of elements 10, 20, 30 to a receiver or decoder stage consisting of elements 50, 60 over a transmission channel 40.

Said sender includes a source 10 of symbols  $\underline{i}$ ,  $\underline{j}$ , etc. that can be generated independently, in which case the source is known as a source without memory, or in a dependent manner, for example according to a first order Markov model that reflects the link between two consecutive symbols. In a video coder, these symbols  $\underline{i}$ ,  $\underline{j}$ , etc. may correspond to texture movement coefficients, for example, quantized to yield a certain number of discrete values.

Said source 10 is followed by a video coder 20 represented by a variable length code (VLC) table, for example that standardized in the MPEG4 video standard. This VLC table is used in the source 10 to code symbols as digital data.

Finally, channel coding, for example convolutional parallel turbocoding, is applied to digital data from the coder 20 to protect it against interference induced during its transmission over the channel 40.

The transmission channel 40 is a noisy channel modeled by a simple Gaussian additive white noise channel, for example.

The receiver or decoder stage includes a combined channel-source decoder 50 which estimates the source statistic. Digital data is fed from the combined decoder 50 to a VLC decoder 60, which could be that of the MPEG4 video decoder, to supply at the output of the decoder an estimate of the values of the symbols  $\underline{i}$ ,  $\underline{j}$ , etc. from the source 10.

The combined channel-source decoder 50 shown in bold in Figure 1 and the decoding method that it uses constitute the subject matter of the present invention.

The combined decoder 50 is described in more detail next with reference to Figure 2.

The Figure 2 diagram shows that the decoder 50 includes a channel decoder 51, preferably of the trellis type, adapted to produce flexible *a posteriori* probability (APP) information. A threshold 52 is applied to the noisy output data to restore said data to the form of digital data consisting of 0 bits and 1 bit. A table-based VLC decoder 53 transforms the received bits into symbols  $\underline{i}$ ,  $\underline{j}$ , etc.

The statistics of the symbols  $\underline{i}$ ,  $\underline{j}$ , etc. from the source are estimated iteratively by means of a histogram generator 54 for calculating symbol probabilities, which are either stationary probabilities  $p(i)$  in the case of a model without memory or transition probabilities  $p(i/j)$  in the case of a first order Markov model.

Note also the presence of a module 56 for symbol probability to bit probability conversion with the VLC tree adapted to inject bit level probabilities into the channel decoder 51. This converter module 56 is the same as the module used in European patent 1 230 736. However, in the context of the invention, as shown in Figure 2, this module, preceded by the histogram generator 54, is used on each decoding iteration to estimate the source 10, in contrast to what is proposed in the above patent, where it is used only once, on the assumption that the channel decoder 51 knows the source probabilities.

Figure 3 is a diagram of one particular embodiment of the combined decoder 50 from Figure 2 in the context of channel coding using the turbocoding technique, this decoder including a second convolutional channel decoder 51' in addition to the convolutional channel decoder 51, each of these convolution channel decoders being associated with a convolutional channel coder (Figure 1 channel coder 30). The change from one of the channel

coders or decoders to the other is effected in accordance with an interleaving law E or the inverse law E\*.

On each turbodecoding iteration, a threshold is applied to the APP at the output of the second  
 5 convolutional decoder 51'. The bits above the threshold 52 are used to retrieve the symbols  $\underline{i}$ ,  $\underline{j}$ , etc. using the VLC coding table 53. A histogram generator 54 then indicates the number of transmissions of each symbol or stores the previous symbol decoded and indicates the  
 10 number of transmissions of each successive pair of symbols.

This histogram generator 54 can therefore calculate stationary probabilities  $p(i)$  and probabilities  $p(i/j)$  of transitions between symbols (if the source is assumed to  
 15 use a first order memory). These probabilities are then used to calculate the VLC tree branch probabilities. This calculation is described in detail in European patent 1 230 736 and carries out the symbol-bit conversion shown in Figure 3, which is indispensable if  
 20 it is to be possible to insert these source probabilities, which at this stage are in the form of VLC tree branch probabilities, into the corresponding stages of the decoding trellis of the first convolutional channel decoder 51.

These probabilities are then inserted as *a priori* probabilities into the Max-Log-MAP decoding algorithm executed on the trellis of the convolutional decoder. They improve the decoding of the convolutional code. The process resumes on the next turbocode iteration, refining  
 30 the source symbol probabilities  $p(i)$  and  $p(i/j)$  and therefore the source *a priori* probabilities used for turbodecoding.

The stationary and transition probabilities associated with the symbols are initialized assuming a  
 35 uniform distribution, although other solutions may be envisaged. Moreover, to limit error propagation, it is possible to packetize the data, for example into packets

of  $80 \times 80$  bits equal to the size of the turbocode interleaver E. The Figure 3 diagram corresponds to a decoding method of type d).

5 Tandem decoding of type a) is effected if the blocks represented in bold in Figure 3 are eliminated, in other words if the decoder 50 works with no *a priori* knowledge of the source, and if only a thresholding operation and hard decoding based on a VLC table are effected on the last iteration.

10 Finally, the situation is of type b) if it is assumed that the first channel decoder 51 has a perfect knowledge of the source 10 and uses both the structure of the VLC tree and the exact source statistic, instead of a simple estimate as in a situation of type d).

15 Figures 4 and 5 show the results of the above three methods for two different sources.

As shown in Figure 4, for a Markov source with three symbols as proposed by Murad and Fuja, the improvement in the signal-to-noise ratio ( $E_b/N_0$ ) of the combined source-channel coding and/or decoding method proposed by the  
20 invention compared to the tandem method of type a) is of the order of 2 dB for the third turbodecoder iteration for a bit error rate (BER) of  $10^{-3}$ .

Moreover, the results achieved with the combined  
25 decoding method and the combined decoder of the invention in practice coincide with the feasible upper performance limit for a system of type a).

Figure 5 shows the results for a Gaussian Markov source with a correlation coefficient of 0.9 uniformly  
30 quantized over four levels. The improvement achieved by the invention is again 2 dB for a BER of  $10^{-3}$  on the third turbocode iteration. The results are again virtually coincident with the theoretical limit for a system of type b), or even better given the relative inaccuracy of  
35 the simulation conditions.